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Engineering Training Group, 6 Flinders Street, Melbourne, Victoria, 3000

ELECTRICAL MEASUREMENT PRINCIPLES

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1. INTRODUCTION.

1.1 The word "Measurements" is often used in telecommunications when referring to the process of using instruments to measure and compare electrical quantities and waveshapes. Since the installation and maintenance of telecommunication equipment often involves this process, it is essential that you understand the basic principles involved in obtaining and interpreting electrical measurements.

1.2 The increasing complexity of telecommunications equipment has led to the development of complex measuring equipment, and many different types and models are available. However, in the early stages of training the measuring instruments used are relatively simple and easy to use, provided you observe a few basic rules.

1.3 This paper introduces the subject of electrical measurements to the point where you will be able to recognise the various basic measuring instruments, and, in conjunction with practical work, be able to use them in typical situations.

2. GENERAL.

2.1 GENERAL. In the installation and maintenance of telecommunications equipment it is necessary to measure:

- Current.
- Voltage.
- Resistance.
- Power.
- Frequency.
- Impedance.

Also, facilities are required for examining the shape of electrical waveforms. Most of the measurements you will make can be related to the measurement of one of the above basic quantities.

2.2 ELECTRICAL UNITS. World-wide standard units, decided upon by International agreement, are used for all electrical measurements, and it is essential that you learn to recognise and use them correctly.

Table 1 summarises the standard units and their symbols.

QUANTITY	NAME OF UNIT	SYMBOL	QUANTITY	NAME OF UNIT	SYMBOL
current	ampere	A	power	watt	W
voltage	volt	V	frequency	hertz	Hz
resistance	ohm	Ω	impedance	ohm	Ω

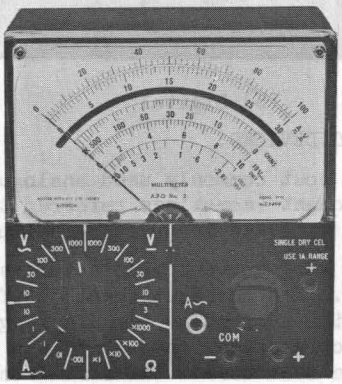
TABLE 1. STANDARD UNITS AND SYMBOLS

In some cases, the standard unit is either too large or too small for convenient use, and it becomes necessary to work in multiples and sub-multiples of standard units. Before proceeding, you should know and understand the meanings of the prefixes (Table 2) which are used to form the multiple and sub-multiple units.

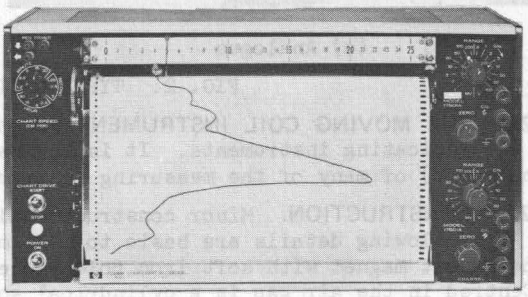
PREFIX	SYMBOL	FACTOR BY WHICH UNIT IS MULTIPLIED	EXAMPLE
giga	G	$1\ 000\ 000\ 000 = 10^{9}$	5 GHz = 5 thousand million hertz.
mega	M	$1\ 000\ 000 = 10^{6}$	4 MHz = 4 million hertz.
kilo	k	$1\ 000 = 10^{3}$	5 kΩ = 5 thousand ohm.
deci	d	$\frac{1}{10} = 10^{-1}$	4 dB = $\frac{4}{10}$ of a bel.
milli	m	$\frac{1}{1\ 000} = 10^{-3}$	7 mA = $\frac{7}{1\ 000}$ of an ampere.
micro	μ	$\frac{1}{1\ 000\ 000} = 10^{-6}$	15 μA = $\frac{15}{1\ 000\ 000}$ of an ampere.
nano	n	$\frac{1}{10^{9}} = 10^{-9}$	24 ns = $\frac{24}{10^{9}}$ of a second.
pico	p	$\frac{1}{10^{12}} = 10^{-12}$	39 pF = $\frac{39}{10^{12}}$ of a farad.

TABLE 2. PREFIXES USED TO FORM MULTIPLE AND SUB-MULTIPLE UNITS.

2.3 MEASURING INSTRUMENTS. An electrical measuring instrument is a device used for determining, and displaying in a suitable manner, the magnitude of an electrical quantity. There are two broad categories of electrical measuring instruments; indicating and recording. Indicating instruments (Fig. 1a) visually indicate the magnitude of the measured quantity; recording instruments (Fig. 1b) inscribe on a chart a permanent or semi-permanent record of the values of the measured quantity with respect to time. The measuring instruments referred to in this paper are all of the indicating type.



(a) Indicating Instrument



(b) Recording Instrument

FIG. 1. MEASURING INSTRUMENTS.

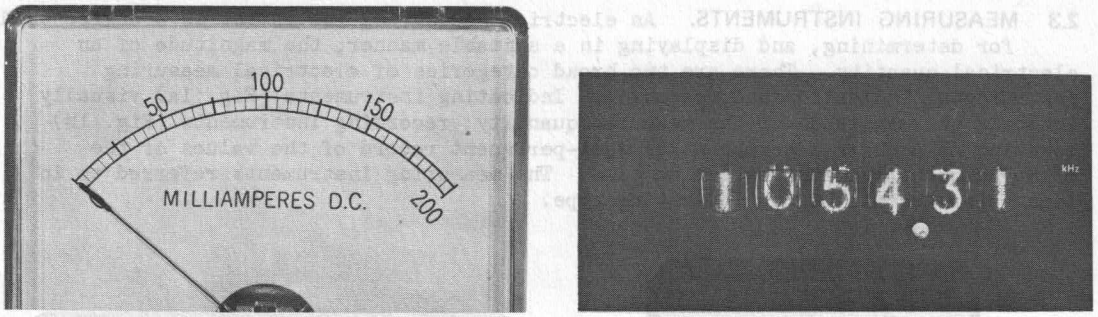
2.4 INSTRUMENT REQUIREMENTS. The main requirements of a measuring instrument are that it should:

- Be easily operated and read.
- Provide accurate readings as quickly as possible.
- Have minimum effect on the circuit when connected for measurement.
- Be self-protecting.
- Be safe to use.

2.5 INDICATING INSTRUMENTS. The speedometer of a car is a measuring instrument with which you are familiar. It indicates speed by means of a pointer moving over a suitably designated scale. The position of the pointer is determined by a signal (obtained or "sensed" from the transmission of the car) which is related to the speed at which the wheels are turning. Electrical indicating instruments operate on the same principle, in that they sense an electrical quantity related to the required measurement, and provide a visual indication to an observer.

All indicating instruments include a sensing device and an indicating device. The sensing device usually makes use of one of the effects of electrical current and voltage. The three effects most commonly used are electromagnetic, electrothermo, and electrostatic.

Two basic types of indicating device are used on electrical measuring instruments. The first type comprises a pointer, light spot, or similar index which moves over a suitably marked dial. An instrument using this type of indicating device is sometimes referred to as an analogue instrument; the word analogue is derived from the fact that the pointer position can represent all the possible values of the measured quantity, within a given range, (Fig. 2a). The second type comprises a display of separate numerals with a light spot to indicate the decimal point. An instrument using this type of indicating device is referred to as a digital instrument (Fig. 2b).

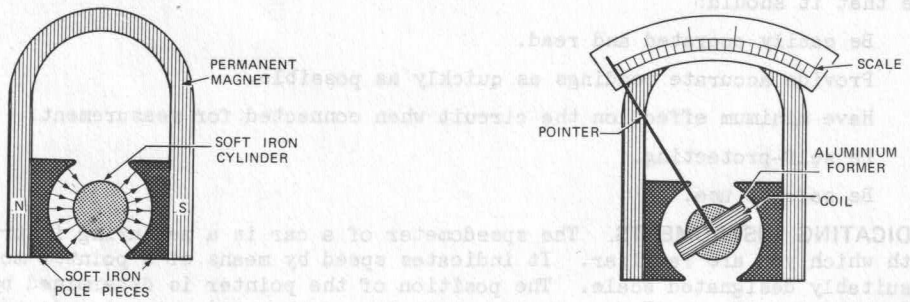


(a) Analogue (b) Digital

FIG. 2. TYPES OF INDICATING DEVICES.

2.6 THE MOVING COIL INSTRUMENT is one of the most commonly used analogue indicating instruments. It is the basic component (sometimes referred to as the movement) of many of the measuring instruments you will use in practical situations.

2.7 CONSTRUCTION. Minor constructional details vary between manufacturers but the following details are basic to most movements. The movement consists of a permanent magnet with soft iron pole pieces providing a circular air gap (Fig. 3a). Centred in the air gap is a cylindrical soft iron core dimensioned so that a small annular gap is left between the pole pieces and the iron core. The soft iron cylinder lowers the reluctance of the air gap between the pole pieces, and, because of its shape, tends to concentrate the field radially. This has the effect of increasing the field intensity and ensures a uniform distribution of flux in the air gap.



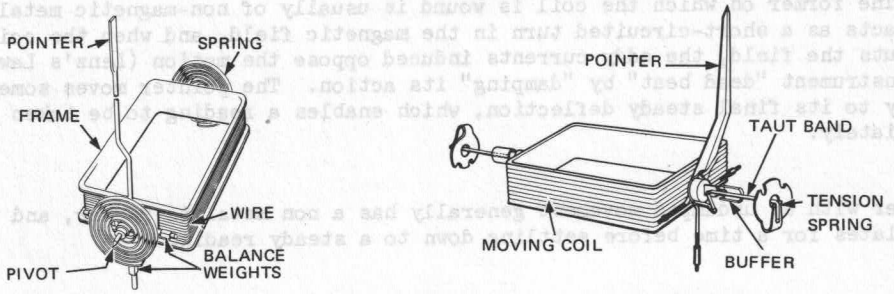
(a) Radial Field (b) Constructional Details

FIG. 3. MOVING COIL METER.

A light rectangular coil of fine wire is wound on an aluminium or similar non-magnetic former and is mounted so that it is free to pivot in the annular air gap of the magnet assembly (Fig. 3b). Attached to the coil is a light pointer which moves over a scale graduated in the units to be measured.

One of two methods is used to mount the moving coil. In one method, hardened steel pivots which rest in jewelled bearings are used and the energising current is led to and from the coil by two light spiral springs (Fig. 4a). One end of each spring is attached to the frame of the instrument, and the other end to the moving coil. The springs also provide the opposing force against which the moving coil acts, and serve to return the pointer to zero.

In the other method, the moving coil is suspended by "taut bands" which are two short strips of special alloy under strong tension (Fig. 4b). The taut bands serve as electrical connections, provide an opposing force, and return the pointer to zero.



(a) Spiral Springs (b) Taut Bands

FIG. 4. METHODS OF MOUNTING THE MOVING COIL.

Fig. 5 shows a sectional view of a typical moving coil instrument. Note the zero adjuster which rotates the front spring to allow the pointer to be positioned on the zero mark of the scale.

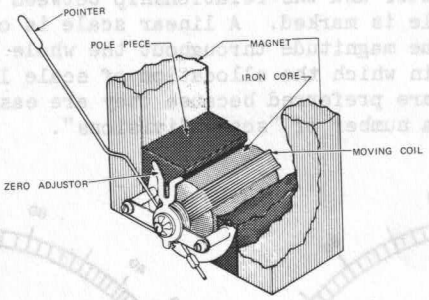
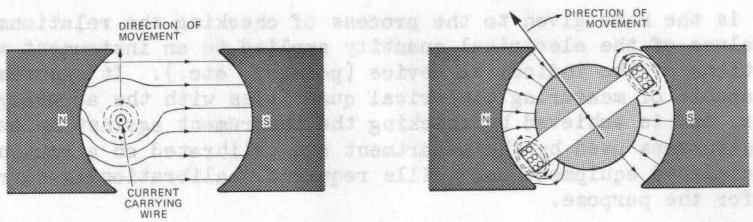


FIG. 5. SECTIONAL VIEW OF MOVING COIL METER.

2.8 OPERATION. The movement uses the "motor principle" of a current-carrying wire in a magnetic field (Fig. 6a). When current flows through the coil, an interaction occurs between the field of the magnet and the field of the moving coil (Fig. 6b). This produces a force which turns the coil on its axis against the force exerted by the springs or taut-bands. When the electrical and mechanical forces are equal, the rotation stops, and the pointer indicates the reading on the graduated scale. Since the restoring force of the springs is proportional to the angle of deflection, and the coil magnetic field is proportional to current flow, the deflection of the pointer is directly proportional to the current, and the scale is graduated in linear (even) steps.



(a) Basic Principle (b) Moving Coil

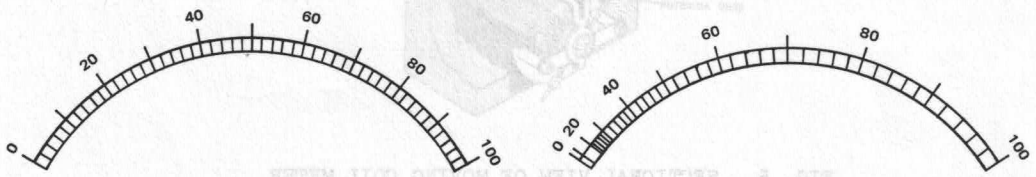
FIG. 6. MOTOR PRINCIPLE OF MOVING COIL.

2.9 The former on which the coil is wound is usually of non-magnetic metal. This acts as a short-circuited turn in the magnetic field, and when the coil moves and cuts the field, the eddy currents induced oppose the motion (Lenz's Law) and make the instrument "dead beat" by "damping" its action. The pointer moves somewhat slowly to its final steady deflection, which enables a reading to be taken immediately.

A meter with an undamped movement generally has a non metallic former, and the needle oscillates for a time before settling down to a steady reading.

2.10 MEASURING INSTRUMENT TERMS. Before proceeding with the various electrical measurements it is essential that you understand the basic terms used in conjunction with measuring instruments. The following paragraphs define the terms commonly used with pointer type (analogue) instruments.

2.11 SCALE. The series of marks and numbers on the dial of an instrument is referred to as the "scale" (Fig. 7). The scale may be linear or non-linear, depending on the type of meter and the relationship between the quantity sensed and the units in which the scale is marked. A linear scale is one in which a given length of scale represents the same magnitude throughout the whole scale length (Fig. 7a). A non-linear scale is one in which the allocation of scale length is not uniform (Fig. 7b). Linear scales are preferred because they are easier to read. Note that the scale is divided into a number of "scale divisions".



(a) Linear Scale (b) Non-linear Scale

FIG. 7. LINEAR AND NON-LINEAR SCALES.

2.12 RANGE. The range of a measuring instrument gives an indication of the values which the instrument is capable of measuring. For example, if a voltmeter has a range of 0-1000V it is capable of measuring voltages between the two figures stated, that is, between 0 and 1000 volts.

2.13 CALIBRATION is the name given to the process of checking the relationship between the values of the electrical quantity applied to an instrument and the corresponding positions of the indicating device (pointer, etc.). It ensures that an instrument is capable of measuring electrical quantities with the accuracy stated by the manufacturer, and is achieved by checking the instrument against an accurate standard. Many instruments used by the Department are calibrated on a routine basis. Because of the specialised equipment and skills required, calibration is carried out at centres set up for the purpose.

2.14 PARALLAX ERROR is the name given to errors which are caused by the eye not being perpendicular to the instrument scale. Some instruments have mirror inserts in the dial to enable the eye to be aligned perpendicularly above the pointer.

2.15 SENSITIVITY. The sensitivity of a measuring instrument gives an indication of the relationship between a change in the quantity being measured and the consequent change in pointer position. A sensitive instrument is one which responds to a small change in the quantity being measured. When designing a sensitive instrument, the designer aims for a minimum change in the quantity to be measured to cause maximum change in pointer position.

3. CURRENT MEASUREMENTS.

3.1 GENERAL. To ensure that telecommunications equipment operates correctly, and that maximum safe current values are not exceeded, it is often necessary to know the value of current in a circuit. In such cases a measuring instrument called an ammeter is inserted in series with the current path (Fig. 8). Connecting the ammeter in series with the circuit ensures that all of the circuit current to be measured flows through the ammeter.

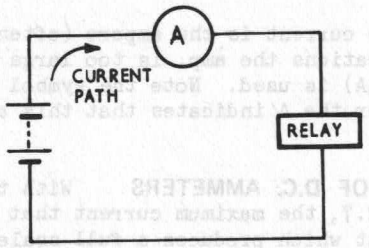


FIG. 8. AMMETER CONNECTION.

Fig. 9 shows a series-parallel circuit comprising a series resistor, and a relay connected in parallel with a lamp and a resistor. To measure the total current in the circuit the ammeter must be connected between points which carry the total circuit current. In this case, the ammeter is connected between points A and B.

To measure only the current via the relay, the ammeter is connected between terminals G & H. Similarly, the current through the lamp or resistor is measured by using terminals EF, or CD, respectively.

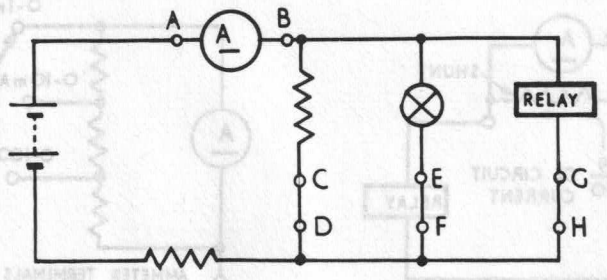


FIG. 9. MEASURING CURRENT.

Figs. 10a and b show current measurements being made in two practical situations. In Fig. 10a the ammeter is measuring the current via a pair of conductors connecting a teleprinter to a telegraph exchange. In Fig. 10b the ammeter is measuring the current via the collector connection of a transistor. Note that in both cases the ammeter is connected directly in series with the current to be measured.

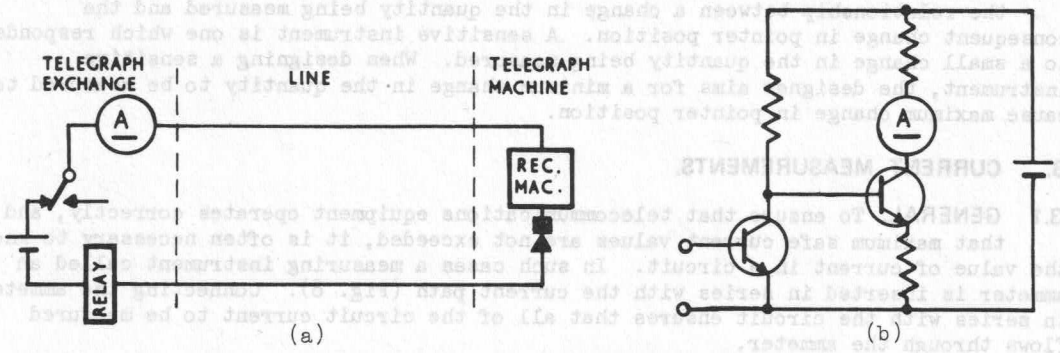
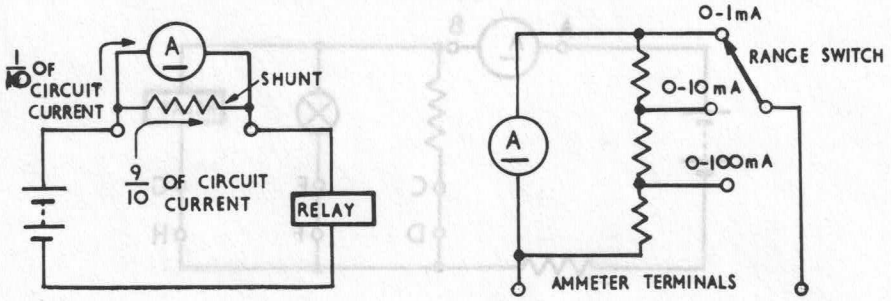


FIG. 10. PRACTICAL CURRENT MEASUREMENTS.

The standard unit used to measure current is the ampere (often abbreviated to amp.), symbol A. In many telecom applications the amp. is too large a unit and either the milliamp. (mA) or a microamp. (μA) is used. Note the symbol used to represent the ammeter in Fig. 10. The bar under the A indicates that this ammeter is used for D.C. measurements.

3.2 EXTENSION OF THE RANGE OF D.C. AMMETERS With the basic moving coil ammeter described in para. 2.7, the maximum current that can be measured is determined by the value of current which produces a full scale deflection of the pointer. In practice, most moving coil instruments give a full scale deflection with 1 mA or less through the moving coil. A meter with such a small current range is obviously limited in usefulness. Special circuit arrangements are employed to allow moving coil ammeters to measure currents larger than the value which produces a full scale deflection when passed through the moving coil.

Fig. 11a shows the basic arrangement. A low value resistor, called a "shunt" is placed in parallel with the basic ammeter and "shunts" some of the current away from the moving coil. By Ohm's Law the current divides between the two paths in the inverse ratio of their resistance. For example, if the resistance of the shunt is 1/9th the resistance of the moving coil, then 9/10 of the current passes via the shunt and 1/10 passes through the moving coil. Because this relationship remains the same for all values of current, the ammeter scale can be set out to read currents up to ten times the value of the current which produces a full scale deflection when passed through the moving coil. This shunt is said to have a multiplying power of 10.



(a) Basic Shunt (b) Tapped Shunt

FIG. 11. AMMETER SHUNTS.

To find the value of the shunt resistance for a given instrument and a given current range the following formula is used:

$$Rs = \frac{Im\ Rm}{Is}$$

where

Rs = resistance of shunt

Rm = resistance of meter

Is = current through the shunt

Im = current through meter for F.S.D.

For example, if an instrument requires 1 mA through its moving coil for full scale deflection and has a resistance of 100 ohms, the shunt resistance required to extend its range to 25 mA is calculated as follows:

$$Rs = \frac{Im\ Rm}{Is}$$

$$= \frac{1 \times 100}{24}$$

$$= 4.167 \text{ ohms.}$$

3.3 In many practical ammeters, particularly portable types, a shunt with several tappings is permanently associated with the meter and is switched into circuit as required by a selector switch. Fig. 11b shows the basic principle of an ammeter which uses a tapped shunt. The instrument in this example has the following ranges:

0-1 mA

0-10 mA

0-100 mA

The tapped shunt (Fig. 11b) is more complex than the basic shunt shown in Fig. 11a, so the formula in para. 3.2 can no longer be applied in its present form.

3.4 POLARITY OF CONNECTION FOR D.C. MEASUREMENTS. With moving coil ammeters the direction of deflection of the pointer is dependent on the direction of the current through the moving coil. Since most ammeters are designed with the zero current point at one end of the scale it is necessary to ensure that current is passed through the moving coil in a particular direction. For this reason the terminals are designated, and the positive terminal should be connected to the more positive side of the circuit and the negative terminal to the more negative side (Fig. 12).

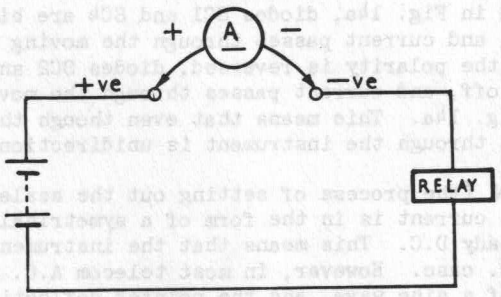
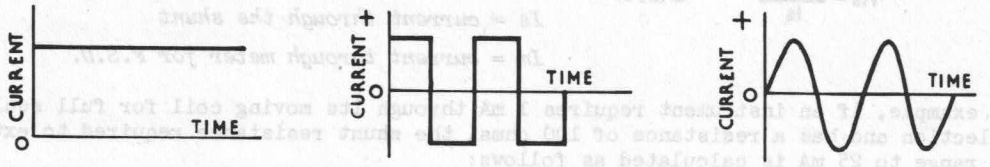


FIG. 12. D.C. AMMETER CONNECTIONS.

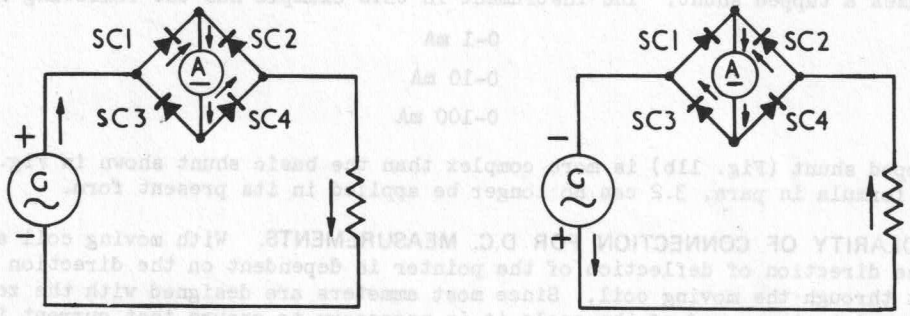
3.5 ALTERNATING CURRENT MEASUREMENTS. In the previous paragraphs the measurement of unidirectional, or direct current has been considered. In many telecom situations it is necessary to measure reversing, or alternating, current. Fig. 13. compares graphical representations of a D.C. current with two forms of alternating current (A.C.).



(a) D.C. (b) A.C. (c) A.C.

FIG. 13. DIRECT AND ALTERNATING CURRENTS.

When the currents represented in Figs. 13. b and c pass through a moving coil instrument, a zero reading results, because the pointer cannot follow the fast changes in current direction and tends to settle at a point half way between the two extreme values, that is, zero current. To use the instrument to measure alternating current the current through the moving coil is converted to D.C. current. One method of achieving this is by the use of a full-wave rectifier as shown in Fig. 14.



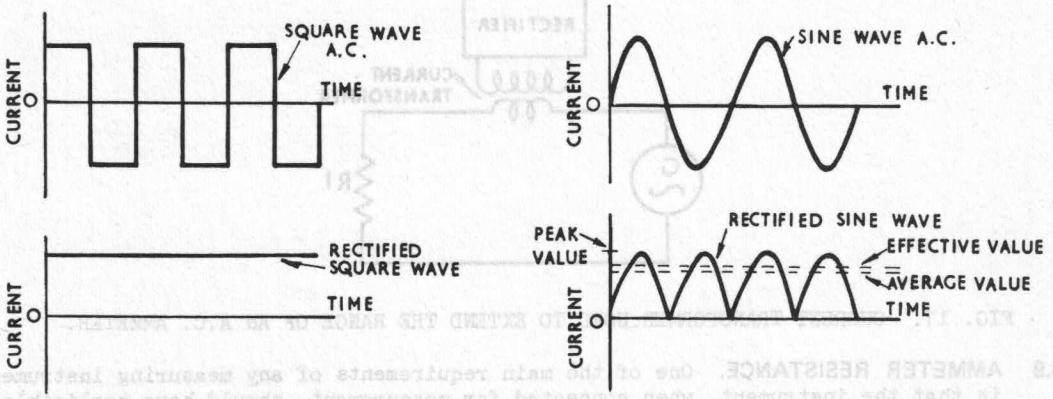
(a) 1st half cycle (b) 2nd half cycle

FIG. 14. MEASURING ALTERNATING CURRENT (FULL-WAVE ARRANGEMENT).

The rectifier circuit comprises four semiconductor diodes. When the polarity of the power supply is as shown in Fig. 14a, diodes SC1 and SC4 are biassed on, diodes SC2 and SC3 are biassed off, and current passes through the moving coil in the direction indicated. In Fig. 14b the polarity is reversed, diodes SC2 and SC3 are biassed on, SC1 and SC4 are biassed off, and current passes through the moving coil in the same direction as shown in Fig. 14a. This means that even though the circuit current is alternating, the current through the instrument is unidirectional.

3.6 SCALE GRADUATION (the process of setting out the scale). Fig. 15a shows that if the circuit current is in the form of a symetrical square wave the rectified current is steady D.C. This means that the instrument scale can be graduated as for the D.C. case. However, in most telecom A.C. measurements the current is in the form of a sine wave, and the pointer deflection is proportional to the average value of the rectified sine wave (Fig. 15b). In practice we are usually interested in the effective value of the sine wave. Because there is a fixed relationship between the average and effective values of a sine wave, the scale is set out so that the instrument directly indicates effective values.

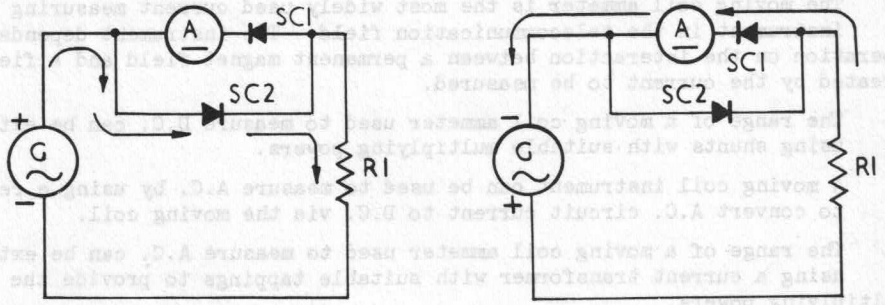
Although the scales of most A.C. instruments are set out to provide readings in effective values, some instruments have scales which provide readings in peak or average values. When measuring A.C. you should always consider two factors; ask yourself "what value is the instrument scale set out to read?" and "what is the waveshape of the current being measured?". A moving coil instrument designed to measure sine wave alternating currents will provide false readings if used to measure other than pure sine waves. Special allowances must be made when measuring other than sine wave A.C. waveshapes on a meter designed to measure pure sine wave currents.



(a) Rectified Square Wave (b) Rectified Sine Wave

FIG. 15. RECTIFIED ALTERNATING CURRENTS.

3.7 Figs. 16a and b show an alternative way of using a moving coil instrument to measure A.C. current. With this arrangement each alternate half cycle is shunted away from the moving coil (Fig. 16a). The other half cycle passes through the moving coil (Fig. 16b) and the pointer deflection is equal to half the average value of the A.C. in circuit. The scale is usually set out to read the effective value of the full wave.



(a) 1st half cycle (b) 2nd half cycle

FIG. 16. MEASURING ALTERNATING CURRENT (HALF WAVE ARRANGEMENT).

3.8 EXTENSION OF THE RANGE OF MOVING COIL A.C. AMMETERS. In para. 3.2 we saw that shunts are used to extend the range of moving coil instruments used to measure direct currents. Shunts cannot be used to extend the range of the rectifier ammeter, because of the difficulty in maintaining a constant relationship between the resistance of the shunt and the resistance of the ammeter-diode combination over the full operating range of the instrument (remember that semiconductor diodes have a non-linear resistance characteristic).

When a rectifier instrument is to be used to measure alternating current in excess of the capability of the moving coil, a current transformer of suitable turns ratio is used (Fig. 17). Where several current ranges are required suitable tappings are provided on the current transformer and a selector switch makes the appropriate connection.

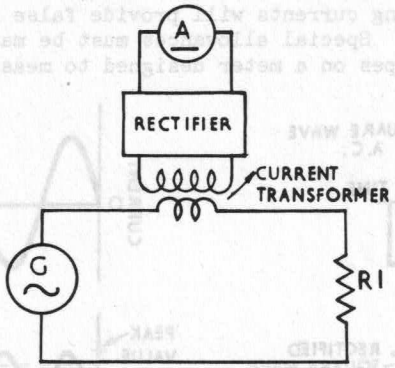


FIG. 17. CURRENT TRANSFORMER USED TO EXTEND THE RANGE OF AN A.C. AMMETER.

3.9 AMMETER RESISTANCE. One of the main requirements of any measuring instrument is that the instrument, when connected for measurement, should have negligible effect on the electrical characteristics of the circuit. Because ammeters are connected in series with circuits it is essential that their resistance be as low as possible to avoid any substantial increase in the circuit resistance. If the ammeter resistance does have an appreciable effect on the circuit resistance, the circuit current is reduced, and the current reading is not a true indication of the normal circuit current.

3.10 SUMMARISING current measurements to this point:

- Ammeters are connected in series with the circuit in which the current is to be measured.
- The moving coil ammeter is the most widely used current measuring instrument in the telecommunication field. The instrument depends for its operation on the interaction between a permanent magnet field and a field created by the current to be measured.
- The range of a moving coil ammeter used to measure D.C. can be extended by using shunts with suitable multiplying powers.
- A moving coil instrument can be used to measure A.C. by using a rectifier to convert A.C. circuit current to D.C. via the moving coil.
- The range of a moving coil ammeter used to measure A.C. can be extended by using a current transformer with suitable tappings to provide the required multiplying powers.
- Ammeter resistance should be low compared with the resistance of the circuit in which measurements are being taken.

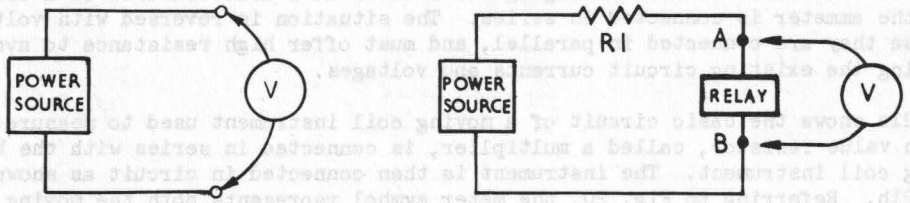
3.11 OTHER CURRENT MEASURING INSTRUMENTS. Other instruments used to measure current include the:

- Moving iron ammeter.
- Thermocouple ammeter.
- Electronic ammeter.
- Dynamometer ammeter.
- Cathode ray oscilloscope.
- Digital ammeter.

These instruments are explained in other publications.

4. VOLTAGE MEASUREMENTS.

4.1 GENERAL. Voltage measurements are often made to assist in the installation and maintenance of telecom equipment. The two basic situations in which voltages are measured are the measurement of the voltage of a power source (Fig. 18a), and the measurement of the voltage across a component or network connected to a power source (Fig. 18b). In both cases the measuring instrument is connected across the points between which the voltage is to be measured. In other words, the measuring instrument is placed in parallel with the power source, the component, or the network.



(a) Voltage of Power Source (b) Voltage across a component

FIG. 18. TYPICAL VOLTAGES TO BE MEASURED.

The measuring instrument most frequently used to measure voltage is referred to as a voltmeter. Fig. 19 shows a series parallel circuit comprising a series resistor, and relay connected in parallel with a lamp and resistor. To measure the voltage supplied by the power source (battery) a voltmeter is connected directly across its terminals (points A and B). To measure the voltage across the series resistor R1 the voltmeter is connected in parallel with the resistor (points C and D). Because the voltages across the relay, the lamp and resistor R2 are all of the same value, the voltage across these components is measured by connecting the voltmeter between points E and F.

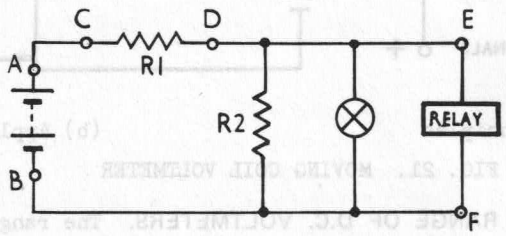
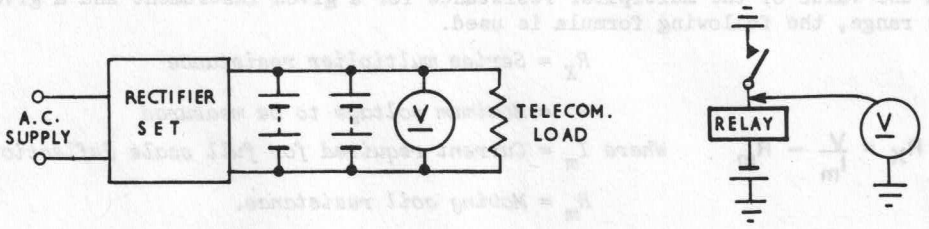


FIG. 19. VOLTAGE MEASURING POINTS.

Figs. 20a and 20b show voltage readings being made in two practical situations. In Fig. 20a, the voltmeter is measuring the voltage being supplied from a D.C. no-break power installation. In Fig. 20b a voltmeter is being used to check the continuity of the coil of a relay in a relay set.



(a) (b)

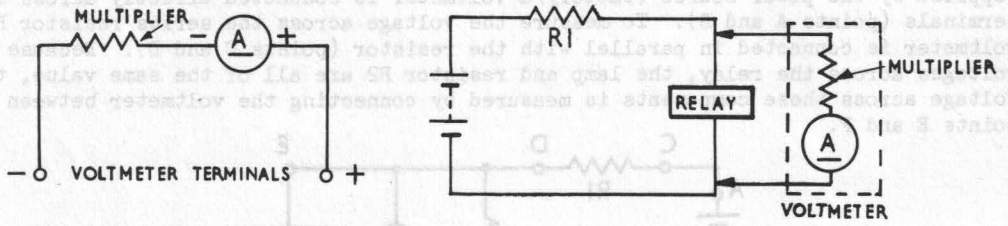
FIG. 20. PRACTICAL VOLTAGE MEASUREMENTS.

The standard unit used to measure voltage is the volt, symbol V. In many telecom situations the volt is too large a unit and either the millivolt or the microvolt is used. In a few cases the volt is too small a unit and the kilovolt is used. Note the symbol used to represent the voltmeter shown in Fig. 20. The bar under the V indicates that this voltmeter is used for D.C. measurements.

4.2 MOVING COIL VOLTMETER. The instrument most frequently used to measure voltage is the moving coil voltmeter. This instrument is a modification of the moving coil ammeter. With ammeters, we saw that the instrument must have a very low value of resistance to avoid changing the electrical characteristics of a circuit when the ammeter is connected in series. The situation is reversed with voltmeters because they are connected in parallel, and must offer high resistance to avoid altering the existing circuit currents and voltages.

Fig. 21a shows the basic circuit of a moving coil instrument used to measure voltage. A high value resistor, called a multiplier, is connected in series with the basic moving coil instrument. The instrument is then connected in circuit as shown in Fig. 21b. Referring to Fig. 20, the meter symbol represents both the moving coil and the associated multiplier.

The deflection of the instrument pointer is determined by the current through the multiplier and the moving coil. The current, in turn, is proportional to the voltage being measured, so that there is a definite relationship between the pointer deflection and the voltage being measured. Because of this relationship, the scale of the instrument can be set out to indicate voltage.



(a) Basic principles (b) Application

FIG. 21. MOVING COIL VOLTMETER

4.3 EXTENSION OF THE RANGE OF D.C. VOLTMETERS. The range of a D.C. voltmeter is extended by changing the resistance of the multiplier. For example, the range of a voltmeter having a full scale deflection of 100 volt can be doubled to 200 volt by replacing the multiplier with another multiplier, so that the total resistance of the meter plus the multiplier is doubled. When the resistance of the instrument is doubled, the voltage required to produce full scale deflection is also doubled.

To find the value of the multiplier resistance for a given instrument and a given voltage range, the following formula is used.

$$R_X = \frac{V}{I_m} - R_m$$

R_X = Series multiplier resistance

V = *Maximum voltage to be measured*

Where I_m = Current required for full scale deflection

R_m = Moving coil resistance.

EXAMPLE. A 1 mA moving coil meter has a resistance of 100 ohms. What is the resistance of the series multiplier which will enable the meter to read 5 volts full scale?

$$R_X = \frac{5 \times 1000}{1} - 100$$

$$R_X = 4900 \text{ ohms.}$$

When calculating multiplier values, the resistance of the meter may be neglected when it is considerably smaller than that of multiplier (say less than 1%). In this case, the formula is simplified as follows:

$$R_X = \frac{V}{I_m}$$

Voltmeters are often supplied with several multipliers which are switched into circuit, as required, by a selector switch. Fig. 22 shows the basic principle of a voltmeter with three multipliers providing the following ranges.

0 - 10 V (multiplier with power of 10)
0 - 100 V (multiplier with power of 100)
0 - 1000 V (multiplier with power of 1000)

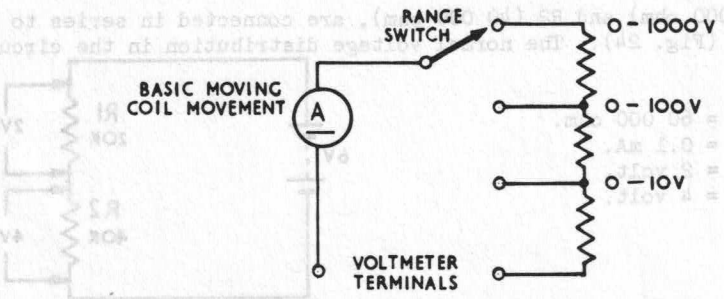
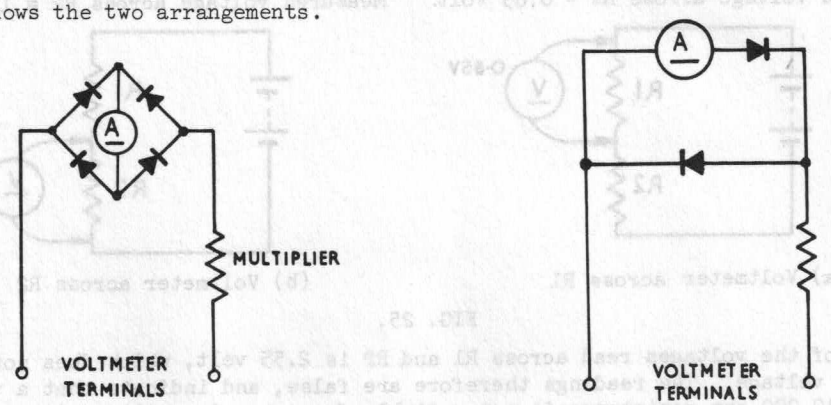


FIG. 22. VOLTMETER MULTIPLIERS.

4.4 POLARITY OF CONNECTION FOR D.C. MEASUREMENTS. Similar to the moving coil ammeter, the direction of deflection of the pointer is dependent on the direction of the current through the moving coil. Therefore, it is necessary to ensure that the positive terminal of the meter is connected to the more positive side of the circuit, and the negative terminal is connected to the more negative side of the circuit.

4.5 ALTERNATING VOLTAGE MEASUREMENTS. The D.C. moving coil voltmeter can be converted to an A.C. voltmeter in the same way as the D.C. ammeter is converted to read alternating current. Either a full or half wave rectifier is used to convert the A.C. voltage being measured to a D.C. voltage across the moving coil of the meter. Fig. 23 shows the two arrangements.



(a) Full wave (b) Half wave

FIG. 23. MEASURING ALTERNATING VOLTAGE.

Note that the multiplier is connected in series with the moving coil and the diodes. The range of an A.C. voltmeter is extended in the same way as the D.C. voltmeter. The non-linear resistance characteristic of the diodes does not present a problem on most A.C. voltmeters because diode resistance is "swamped" by the comparatively high value of resistance offered by the multiplier.

4.6 SCALE GRADUATION. As in the case of alternating current measurements consideration must be given to how the instrument scale has been set out. In most situations effective voltage values are required, and for this reason most moving coil voltmeters have scales which indicate effective values. The waveshape of the voltage must also be considered. Special allowances must be made when reading voltages with waveshapes which are not sine waves.

4.7 VOLTMETER RESISTANCE. Because voltmeters are connected in parallel with components and networks it is essential that they offer maximum resistance to avoid disturbing existing circuit currents and voltages. This is particularly so when using voltmeters in high resistance circuits. The following example illustrates the effect of a low resistance voltmeter used on a high resistance circuit.

Two resistors, R1 (20 000 ohm) and R2 (40 000 ohm), are connected in series to a D.C. power supply of 6 volt (Fig. 24). The normal voltage distribution in the circuit is calculated as follows:

Total resistance = 60 000 ohm.
Circuit current = 0.1 mA.
Voltage across R1 = 2 volt.
Voltage across R2 = 4 volt.

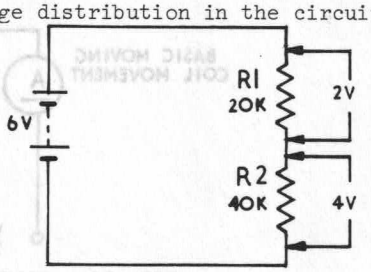
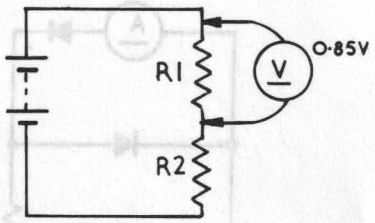


FIG. 24.

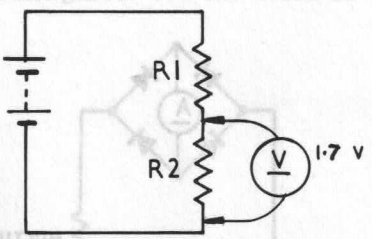
When the voltages across R1 and R2 are measured with a voltmeter with a resistance 10 000 ohms, the normal circuit values are upset and false readings are obtained.

Voltmeter across R1 (Fig. 25a)
Joint resistance of R1 and meter = 6666 ohm
Total resistance of circuit = 46 666 ohm
Circuit current = 0.128 mA.
Measured voltage across R1 = 0.85 volt.

Voltmeter across R2 (Fig. 25b)
Joint resistance of R2 and meter = 8000 ohm
Total resistance of circuit = 28 000 ohm
Circuit current = 0.214 mA.
Measured voltage across R2 = 1.7 volt..



(a) Voltmeter across R1



(b) Voltmeter across R2

FIG. 25.

The total of the voltages read across R1 and R2 is 2.55 volt, which does not equal the supply voltage. The readings therefore are false, and indicate that a voltmeter with only 10 000 ohm resistance is not suitable for measuring voltage in this circuit. In general, the resistance of the voltmeter should be many times greater than the impedance of the circuit or circuit component across which it is connected.

Manufacturers of measuring instruments often specify the input resistance of moving coil voltmeters in ohms per volt. To determine the resistance of a voltmeter on a particular range, multiply the maximum voltage value for that range by the ohms per volt specification. For example, the resistance of a 1000 ohm per volt instrument on the 0-10 V range is 10 × 1000 = 10 000 ohm. This means that when the instrument is used with the selector switch in the 0-10 V range, the instruments' resistance is 10 000 ohm. Similarly, on the 0-100 V range the instruments' resistance is 100 000 ohm.

4.8 VOLTAGE WITH RESPECT TO A REFERENCE POINT. When measuring voltage, the measurement is often made relative to a reference point in the circuit; that is, the voltage is measured between a selected point and the reference point. For example, in Fig. 26a the earth is used as the reference point, and voltage is measured between earth and points A and B in the circuit.

In D.C. measurements it is possible to specify whether the voltage is positive or negative with respect to the reference point. In Fig. 26a point A is 6 volt negative with respect to the reference point and point B is 2 volt negative with respect to the reference point. The use of a common reference point allows comparisons to be made of voltages at various points in the circuit. Since only one lead has to be moved from point to point it also simplifies connection of the voltmeter.

Note that if a different reference point is chosen, the voltage readings and polarities may change. For example, in Fig. 26b the negative terminal of the power supply is chosen as the reference point. Point A is now 4 volt positive with respect to the reference point and point B is 8 volt positive.

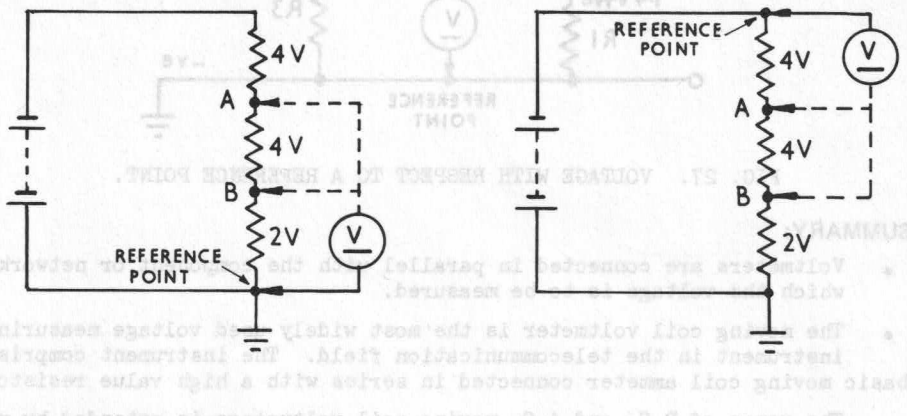


FIG. 26. MEASURING VOLTAGE WITH RESPECT TO A REFERENCE POINT.

In Figs. 26a and b the voltage between points A and B is found by subtracting the two readings taken with respect to a particular reference point. In Fig. 26a, 6 volt - 2 volt gives 4 volt. Since A is more negative than B, we say A is 4 volt negative with respect to B. Alternatively, we can say B is 4 volt positive with respect to A. Note that polarities cannot be stated when reading voltages in an A.C. circuit.

Fig. 27 shows how voltage readings with respect to (w.r.t.) a reference point are taken in a practical D.C. circuit. A reference point is selected and the appropriate voltmeter lead is connected to this point (negative terminal of the power supply). The other terminal is used to connect the meter to points in the circuit at which voltage readings are required.

The information obtained by reading the voltages at the points indicated is as follows:

- Emitter of SC1 is 1.4 V positive w.r.t. reference point.
- Collector of SC1 and base of SC2 are 4 V positive w.r.t. reference point.
- Emitter of SC2 is 3.6 V positive w.r.t. reference point.
- Collector of SC2 is 6 V positive w.r.t. reference point.

From these readings it is found that:

- The collector of SC1 is 3.6 V positive w.r.t. the emitter.
- The base of SC2 is 0.4 V positive w.r.t. the emitter.
- The emitter of SC2 is 2.4 V negative w.r.t. the collector.

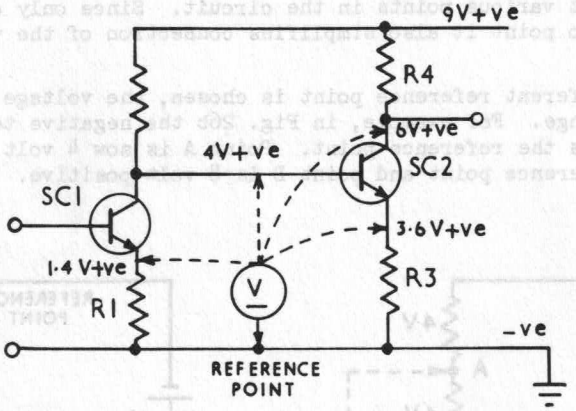


FIG. 27. VOLTAGE WITH RESPECT TO A REFERENCE POINT.

4.9 SUMMARY:

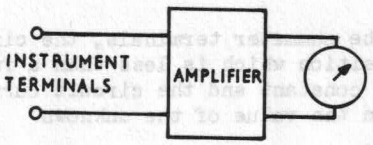
- Voltmeters are connected in parallel with the component or network across which the voltage is to be measured.
- The moving coil voltmeter is the most widely used voltage measuring instrument in the telecommunication field. The instrument comprises a basic moving coil ammeter connected in series with a high value resistor.
- The range of D.C. and A.C. moving coil voltmeters is extended by using series resistors referred to as "multipliers."
- A moving coil voltmeter can be used to measure A.C. voltage by using a rectifier to convert the A.C. circuit voltage to D.C. voltage across the moving coil.
- The resistance of a voltmeter should be many times greater than the impedance of the component or network across which the instrument is connected.
- Voltages are often read with respect to (w.r.t.) a reference point. In D.C. circuits the polarity as well as the magnitude is often stated.

4.10 OTHER VOLTAGE MEASURING INSTRUMENTS. Other instruments used to measure voltage include the:

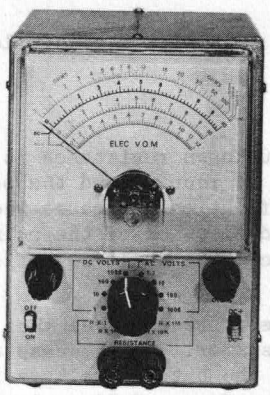
- Cathode ray oscilloscope.
- Moving iron voltmeter.
- Electrostatic voltmeter.
- Thermocouple voltmeter.
- Dynamometer voltmeter.
- Electronic voltmeter.
- Digital voltmeter.

The cathode ray oscilloscope and the electronic voltmeter are used extensively for voltage measurements and are briefly described in section 7 and para. 4.11 respectively. The other instruments are described in other publications.

4.11 ELECTRONIC VOLTMETERS. Electronic voltmeters are used extensively in telecommunications measurements, particularly in situations where it is essential that the voltmeter has a high resistance (a typical instrument has an input impedance of 10 MΩ). These instruments usually comprise an amplifier and the basic moving coil instrument. (Fig. 28a). The amplifier is designed to amplify very low level signals to a level suitable for application to the moving coil. Because of this, the instrument is very sensitive; that is, the moving coil responds to a very small change in measured voltage. Electronic voltmeters have another important feature in that they have a very wide frequency range. Fig. 28b shows a typical instrument.



(a) Basic principle



(b) Instrument

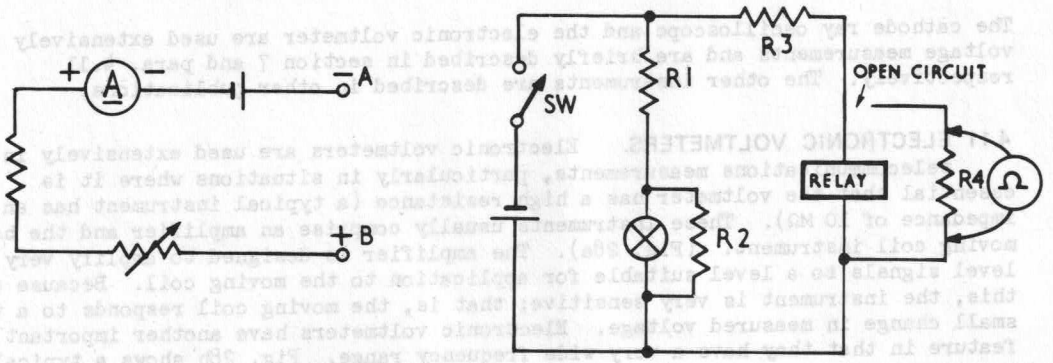
FIG. 28. ELECTRONIC VOLTMETER

5. RESISTANCE MEASUREMENTS.

5.1 GENERAL. Because the resistance of a component or network determines the current through, and the voltage across the component or network, it is essential to have some means of measuring resistance. Resistance measurements assist in the installation and maintenance of telecom equipment, particularly in the location of faults. The two instruments most commonly used are the ohmmeter and the wheatstone bridge.

The standard unit used to measure resistance is the ohm, symbol Ω. In many applications the ohm is too small a unit and either the kilohm (kΩ) or the megohm (MΩ) is used.

5.2 OHMMETER. Fig. 29a shows the basic principle of operation of a typical ohmmeter. A sensitive moving coil ammeter is connected in series with a battery, a fixed resistor, and a variable resistor. The circuit components are selected so that when the terminals (A and B) are short-circuited, a full scale deflection of the pointer can be obtained by varying the circuit current under the control of the variable resistor. The full scale deflection corresponds to the condition where there is zero resistance between the terminals, and the scale is marked accordingly. That is, the full scale deflection position of the instrument pointer indicates zero resistance.



(a) Basic principle (b) Measuring Resistance with Ohmmeter

FIG. 29. OHMMETER.

When an unknown resistance is connected between the ohmmeter terminals, the circuit current is reduced and the pointer takes up a position which is less than a full scale deflection. Because the circuit voltage is constant and the circuit current and the deflection of the pointer are dependent on the value of the unknown resistance, the scale is set out directly in ohms.

The range of resistances that can be read is extended by changing the value of the fixed resistor. In the case of very high resistances, it may be necessary to increase the battery voltage in order that sufficient current flows via the moving coil to produce a full scale deflection when the terminals are short-circuited.

5.3 RESISTANCE MEASUREMENTS USING AN OHMMETER. To measure resistance with an ohmmeter the instrument terminals are connected across the unknown resistance as shown in Fig. 29b.

Because false readings are obtained if current via the moving coil is drawn from any source other than the internal battery, it is essential that ohmmeters are used on circuits only after all power supplies are either switched off or disconnected.

It is also essential to check that only the relevant component or circuit is connected between the ohmmeter terminals. When other parallel paths exist a false reading will be obtained. For example, to measure the resistance of R4 in Fig. 29b it is necessary to either disconnect one terminal of R4 or to open the parallel paths via the relay and R3.

5.4 WHEATSTONE BRIDGE. The wheatstone bridge is used for resistance measurements and depends on the principles described in this paragraph for its operation. These principles also apply to other measuring instruments which depend on bridge circuit principles.

Fig. 30a shows a simple bridge circuit comprising four resistors of equal value (R1 = R2 = R3 = R4) and a power supply of 12 volt D.C. Because the circuit is a parallel circuit with two paths each consisting of two resistors of equal value, the potential drop across each resistor is 6 volts (see Fig. 30b).

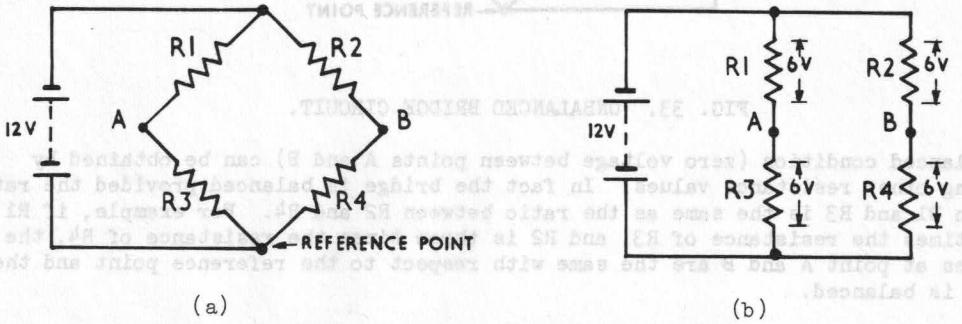


FIG. 30. BRIDGE CIRCUIT.

To simplify the explanation, the junction of R3 and R4 is designated as a reference point. The potential at point A with respect to the reference point is 6 volt negative (Fig. 31). Similarly the potential at point B with respect to the reference point is 6 volt negative. Because both A and B are at the same potential with respect to a common reference point there is no potential difference between A and B, and no deflection would be obtained on a voltmeter connected between the two points. The bridge is said to be "balanced" under these conditions.

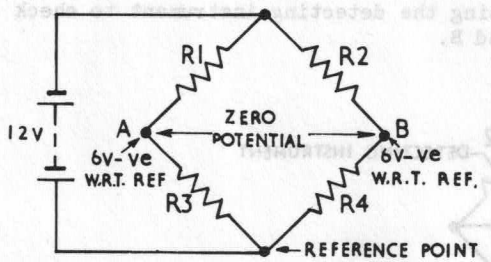


FIG. 31. BALANCED BRIDGE.

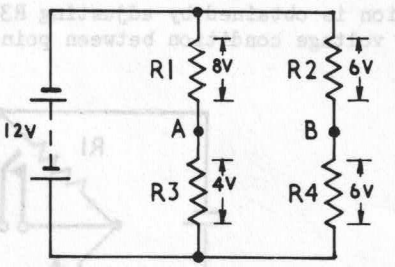


FIG. 32. UNBALANCED BRIDGE CIRCUIT.

Consider the effect of changing the value of one of the resistors, (Fig. 32). Suppose the value of R3 is reduced to half its original value. The supply voltage still divides evenly across R2 and R4, but the voltages across R1 and R3 change to values determined by the ratio of the resistance values. Because R1 offers twice the resistance of R3, the voltage divides so that 8 volt appears across R1 and 4 volt appears across R3.

Under these conditions point A is 4 volt negative with respect to the reference point, and point B is 6 volt negative with respect to the reference point (Fig. 33). A voltmeter connected between points A and B would indicate that point B is 2 volt negative with respect to A. The bridge is said to be unbalanced under these conditions.

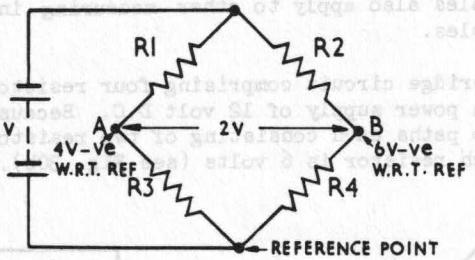


FIG. 33. UNBALANCED BRIDGE CIRCUIT.

The balanced condition (zero voltage between points A and B) can be obtained by choosing other resistance values. In fact the bridge is balanced provided the ratio between R1 and R3 is the same as the ratio between R2 and R4. For example, if R1 is three times the resistance of R3, and R2 is three times the resistance of R4, the voltages at point A and B are the same with respect to the reference point and the bridge is balanced.

Summarising, the bridge is said to be balanced when no voltage exists between points A and B. This condition exists only when the ratio between R1 and R3 is the same as the the ratio between R2 and R4, that is R1/R3 = R2/R4. The bridge is said to be unbalanced when a voltage exists between points A and B, that is R1/R3 $\neq$ R2/R4.

5.5 RESISTANCE MEASUREMENTS USING A WHEATSTONE BRIDGE. One important application of the bridge circuit explained in the previous paragraph is the measurement of resistance. Fig. 34 shows a simple bridge circuit that can be used for measuring resistance. R3 of Fig. 30 is replaced with a calibrated variable resistor (a variable resistor designated so that the resistance of each setting can be read directly) and R4 is replaced with an unknown resistance (Rx). The balanced condition is obtained by adjusting R3 and using the detecting instrument to check for the no voltage condition between points A and B.

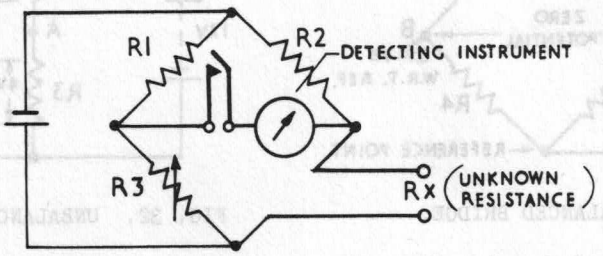


FIG. 34. SIMPLIFIED WHEATSTONE BRIDGE.

Once the balance condition has been obtained, the value of the unknown resistor is found by transposing the formula:

$$\frac{R1}{R3} = \frac{R2}{Rx}$$

$$\therefore \quad Rx = \frac{R2 \times R3}{R1}$$

When R2 = R1, Rx = R3 × 1 = R3. In other words the value of the unknown resistor equals the values indicated by the setting of the calibrated variable resistor R3.

The range of resistance values which can be measured is extended by changing the ratio between R1 and R2. In practice R1 and R2 are known as "ratio arms". Consider the effect of changing the ratio between R1 and R2. From the formula for calculating the unknown resistance, Rx = R3 R2/R1, it can be seen the ratio between R2 and R1 is a multiplying factor. That is, if the bridge is balanced and R2 is ten times the value of R1, the value of the unknown resistor is ten times the value of R3. Practical bridges allow for the selection of a suitable ratio by means of selection switches.

6. MULTIMETERS.

6.1 GENERAL. The multimeter is one of the most commonly used measuring instruments, since it can be used to measure current, voltage and resistance. A wide range of multimeters is used by the Department, but at the time of writing the A.P.O. No. 3 (Fig. 35) is the standard general purpose instrument. The instrument is based on a sensitive moving coil movement which requires 400 μA (0.4 mA) for full scale deflection.

6.2 THE A.P.O. NO. 3 MULTIMETER is self-contained and is designed for use in the face upward position. It has accuracy which is better than ±1% of the full scale value on D.C. ranges and ±2% of full scale value on A.C. ranges. The multimeter is housed in a bakelite case and the batteries required for resistance measurements are in a moulded recess with a removable cover in the rear of the case.

Shunts, multipliers, diodes and batteries are switched into circuit as required to enable the meter to make measurements within the following ranges:

D.C.		A.C.	
CURRENT	VOLTAGE	CURRENT	VOLTAGE
0-1 mA	0-3 V	0-1 mA	0-10 V
0-10 mA	0-10 V	0-10 mA	0-30 V
0-100 mA	0-30 V	0-100 mA	0-100 V
0-1 A	0-100 V	0-1 A	0-300 V
0-10 A	0-300 V	0-10 A	0-1000 V
-	0-1000 V		
RESISTANCE - Approx. 1 ohm to 1 megohm			

In addition provision is made for testing dry cells.

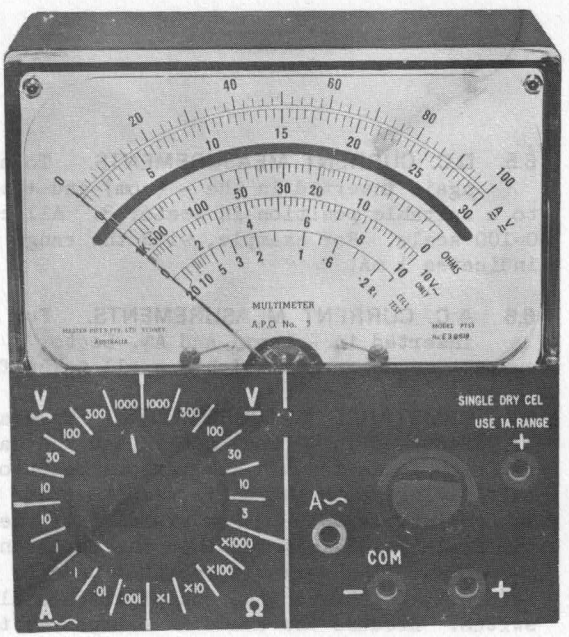


FIG. 35. A.P.O. NO. 3 MULTIMETER.

Fig. 36 shows the face layout of the meter comprising the scale, the operating controls, and the test jacks for the connection of test leads. The scale has a mirror insert to reduce parallax errors and is explained in paras. 6.3 to 6.8. The operating controls comprise a twenty position rotary switch, a variable resistor, and a zero adjuster. The rotary switch moves through a full circle which is divided into four sectors, each of which is further subdivided to provide the required number of positions. The variable resistor is used when making resistance measurements, and the zero adjuster allows mechanical adjustment of the pointer position when the meter is in the rest condition. Four test jacks are used as required to make connections via test leads to the network or component under test.

6.3 D.C. VOLTAGE MEASUREMENTS. To measure D.C. voltages the test leads are inserted in the -(com) and + test jacks. Sector 1 of the range switch is associated with D.C. voltage measurements and is further divided into six separate ranges. The 0-30 and 0-100 scale markings are used as required for all D.C. voltage measurements.

6.4 A.C. VOLTAGE MEASUREMENTS. To measure A.C. voltages, the test leads are inserted in the - (com) and + test jacks, and the range switch is operated to a suitable position in sector 2. The 0-30 and 0-100 scale markings are used for all readings except those associated with the 10 V position of the range switch. For this range a special 0-10 scale is used.

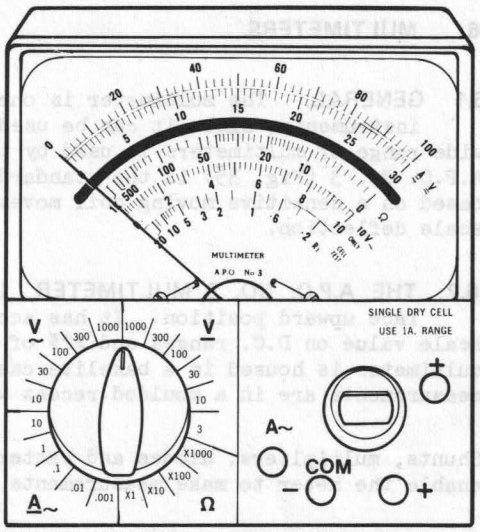


FIG. 36. FACE LAYOUT OF A.P.O. NO. 3.

6.5 D.C. CURRENT MEASUREMENTS. To measure D.C. current, the test leads are again inserted in the - (com) and + test jacks, and the range switch is operated to a suitable position in sector 3. All current measurements are taken from the 0-100 scale. For example, with the range switch on .001, a full scale deflection indicates 1 mA.

6.6 A.C. CURRENT MEASUREMENTS. For A.C. current measurements the leads are inserted in - (com) and A∿. Sector 3 of the range switch is used for A.C. current measurements which are all taken from the 0-100 scale.

6.7 RESISTANCE MEASUREMENTS. To measure resistance, the test leads are inserted in - (com) and +, and the range switch is operated to a suitable position in sector 4. The various positions in sector 4 are designated by a multiplying factor which is used together with the ohms scale reading to determine the resistance value. For example, if the range switch is in the x100 position and the scale reading is 20, then the resistance between the terminals is 20 × 100 = 2000 ohms. The variable resistor used to set the zero ohms point must be adjusted before taking a reading, and after each alteration of the position of the range switch. Because the scale is cramped at the high end, resistance measurements should be made on the ohms range which gives a reading on the scale of between 5 and 50.

6.8 CELL TESTING. Single dry cell tests are made by operating the range switch to the 1 amp position and inserting the test leads between - (com) and the dry cell test jack. The resistance reading taken after 15 seconds shows the approximate internal resistance of the cell, from which the remaining service life can be estimated.

6.9 MULTIMETER CIRCUIT. Fig. 37 shows the circuit of the A.P.O. No. 3 multimeter. Half-wave rectifier D1 is used to convert alternating current to direct current via the moving coil. Rectifier D2 protects the movement against damage due to accidental overload. Under normal conditions the P.D. across the diode is less than 0.1 volt, and the shunting effect of the diode is negligible because of its high forward resistance. In the event of overload, the voltage across the diode increases to a value at which the forward resistance is very small, and the excess current is shunted away from the moving coil. Note that the dotted line between the switch contacts indicates a mechanical interlock, and that all contacts move simultaneously.

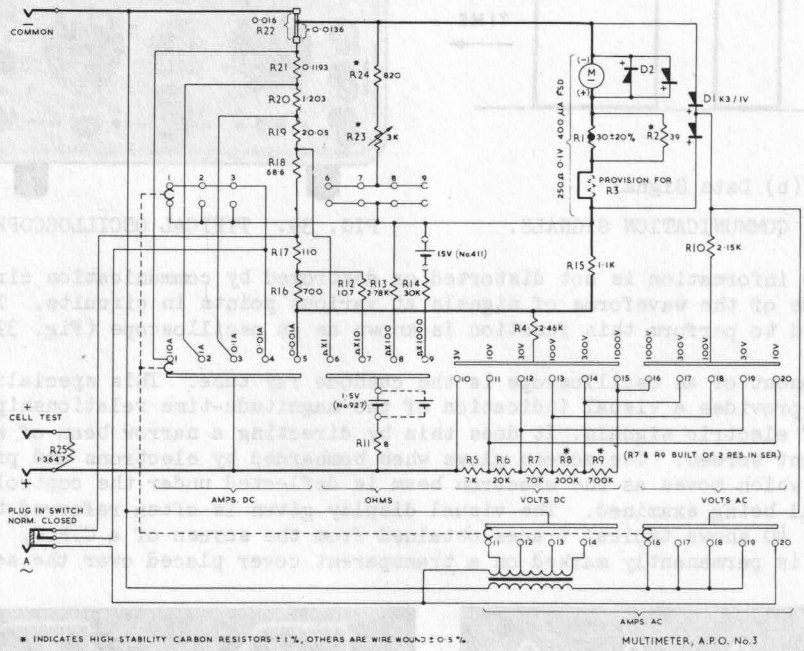
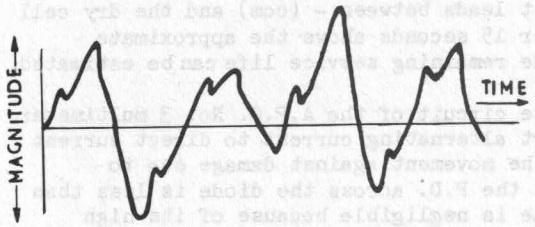


FIG. 37. A.P.O. NO. 3 MULTIMETER.

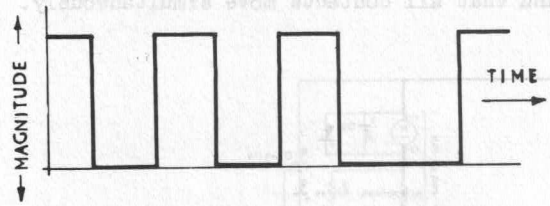
7. WAVEFORM EXAMINATION.

7.1 GENERAL. Telecommunications circuits and equipment transmit information from one point to another by means of electric signals. The information is converted to electric signals at the tranmitting point and carried via communications circuits to the receiving point where it is converted to the original or desired form.

The information at the transmitting point is converted to an electric signal by means of a device which uses the information to control the magnitude of an electric signal from instant to instant. In other words the information is transmitted from one point to another by varying the magnitude of electric signals in relation to time. Fig. 38 shows two examples. Fig. 38a shows a speech signal associated with a telephone conversation and Fig. 38b shows a data signal associated with a computer. In both cases the "intelligence" of the signal is contained in the magnitude-time relationship or waveshape of the signal. The "waveshape" or "waveform" of communication signals are terms commonly used.



(a) Speech Signal



(b) Data Signal

FIG. 38. COMMUNICATION SIGNALS.

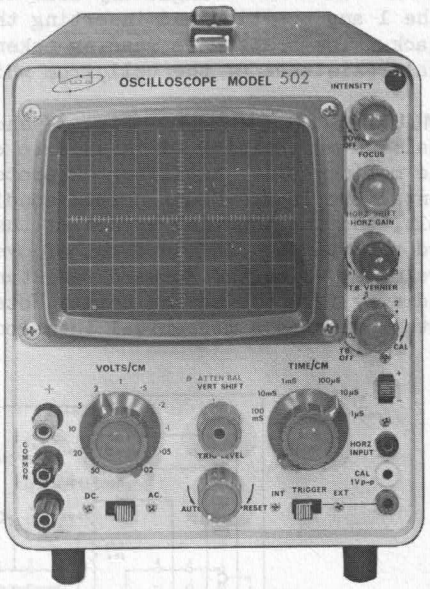


FIG. 39. TYPICAL OSCILLOSCOPE.

To ensure that information is not distorted or destroyed by communication circuits, checks are made of the waveforms of signals at various points in circuits. The instrument used to perform this function is known as an oscilloscope (Fig. 39).

The main component of an oscilloscope is the cathode ray tube. This special purpose electron tube provides a visual indication of the magnitude-time relationship (waveshape) of electric signals. It does this by directing a narrow beam of electrons at a fluorescent screen. The screen glows when bombarded by electrons and produces a spot of light which moves as the electron beam is deflected under the control of the electric signal being examined. The visual display given is often referred to as a "trace". Fig. 40 shows typical traces obtained from the screen of a C.R.O. Note that the grid is permanently marked on a transparent cover placed over the screen.

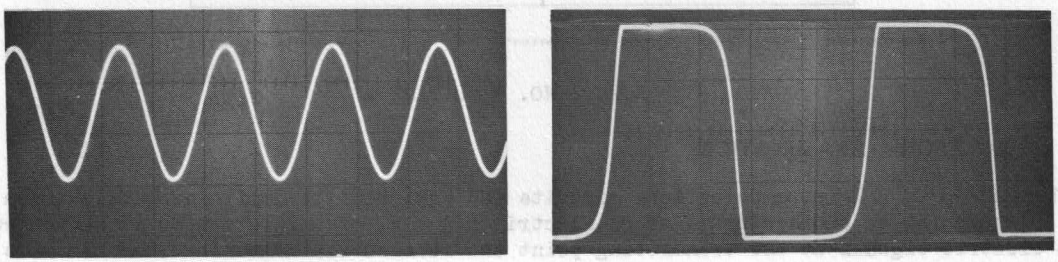


FIG. 40. TYPICAL C.R.O. TRACES

Three main types of information can be obtained from an oscilloscope trace of a communications signal; these are:

- The Shape of the signal (waveform).
- The Voltage of the signal.
- The Frequency of the signal.

Remember that the trace indicates the relationship between the magnitude of an electric signal and time. On the screen of an oscilloscope time is represented on the horizontal or X axis and magnitude is represented on the vertical or Y axis. The oscilloscope can also be used to measure time.

7.2 WAVEFORM EXAMINATION. An oscilloscope is often used to check whether the waveform of a signal at a point in a circuit conforms with what is expected or required at that point. Circuits provided by equipment manufacturers often include waveform diagrams at various checking points to assist in the location of faults. The oscilloscope is often used in conjunction with signal sources (see section 11) to check circuits and locate faults. For example, if a suitable signal is applied at the input to an amplifier and the output signal is compared with the input signal, it can be determined whether the amplifier is distorting the signal. By checking the signal at points between intermediate stages, fault conditions can often be localised. Fig. 41 compares input and output signals of a faulty audio amplifier. Note the difference in shape of the input and output signals.

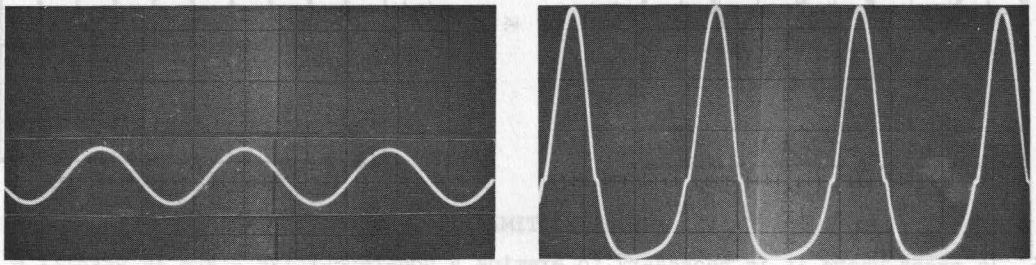
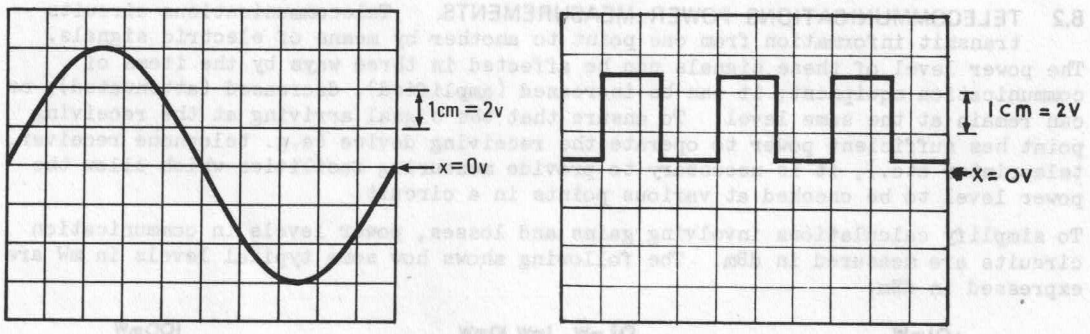


FIG. 41. COMPARISON OF INPUT AND OUTPUT SIGNALS.

7.3 VOLTAGE MEASUREMENT. Since an oscilloscope provides an indication of the magnitude-time relationship of a signal it can be used to read voltage. It is particularly useful when reading voltages of signals with complex waveforms. The vertical axis is used to represent voltage, and on a typical oscilloscope each centimetre of axis can represent voltage values ranging from 10 mV to 50 V. In Fig. 42a each centimetre of axis represents 2 V and the peak to valley voltage is 12 V. Note also that the zero voltage point is preset to correspond with the horizontal axis. In Fig. 42b the signal voltage is at one of two levels, 5 V or 0.5 V.



(a) (b)

FIG. 42. MEASURING VOLTAGE.

7.4 FREQUENCY AND TIME MEASUREMENT. Modern oscilloscopes are calibrated so that the length of the horizontal axis represents one of a selection of times. For example, on a typical instrument, one centimetre of horizontal axis can represent times ranging from 0.2 µs to 2 seconds. Once the time allocation of each centimetre of axis is known, the oscilloscope can be used to measure time and frequency.

In Fig. 43a each centimetre of axis represents 5 ms of time, and one complete cycle of the signal occupies 4 cm of the time axis or 20 ms. The frequency of the signal is obtained by dividing the time for one cycle into one second 1000/20, giving in this case 50 Hz. In Fig. 43b each centimetre of the time axis represents 1 µs, and one complete pulse (including the space condition) occupies 2 centimetres of the axis (that is 2 µs) giving a pulse repetition frequency of 500 kHz.

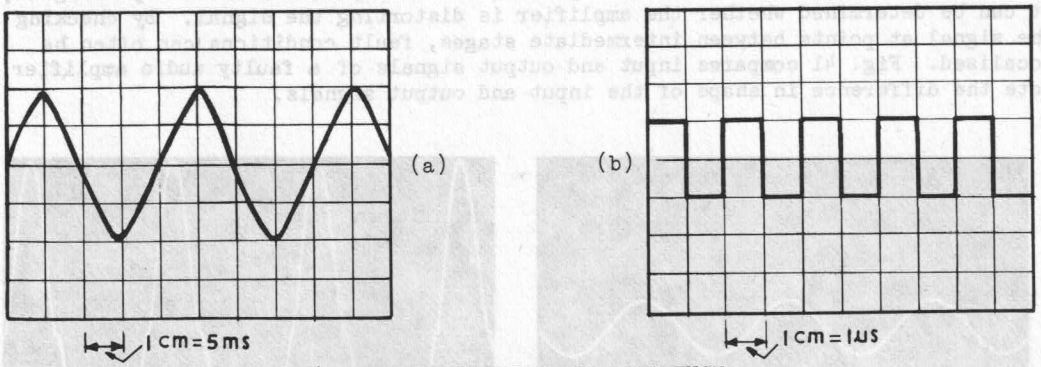


FIG. 43. MESURING TIME AND FREQUENCY.

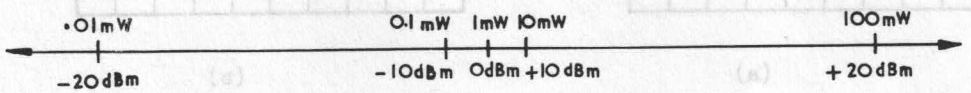
7.5 In cases where it is necessary to examine a non-repetitive trace in detail, a "storage" oscilloscope is used. This instrument has a special screen (extended persistance) on which the trace can be retained for periods up to one hour. Where a permanent record of an oscilloscope trace is required, a camera attachment is provided to enable traces to be photographed. Oscilloscopes are used for many other purposes, including current measurement, fault location, and examination of component and network characteristics. These more specialised uses are described, as required, in other papers.

8. POWER MEASUREMENTS.

8.1 GENERAL. All electrically operated equipment depends for its operation on electric power. In everyday life, the watt is the unit used to measure power, and many electrical appliances are rated in this unit. One instrument used to measure power is called a wattmeter and this instrument operates on the dynamometer principle explained in other papers.

8.2 TELECOMMUNICATIONS POWER MEASUREMENTS. Telecommunications circuits transmit information from one point to another by means of electric signals. The power level of these signals can be affected in three ways by the items of communication equipment; it can be increased (amplified), decreased (attenuated), or can remain at the same level. To ensure that the signal arriving at the receiving point has sufficient power to operate the receiving device (e.g. telephone receiver, teleprinter etc.), it is necessary to provide measuring facilities which allow the power level to be checked at various points in a circuit.

To simplify calculations involving gains and losses, power levels in communication circuits are measured in dBm. The following shows how some typical levels in mW are expressed in dBm.



When measuring power levels in communication circuits it is usual to remove the circuit from traffic, rather than attempt to obtain the required measurements while the circuit is in use by subscribers. Fig. 44 illustrates the principle. An artifical signal of known power is applied at point A, and a level measuring set is used to measure the power level at point B. By comparing the value obtained with a standard set of figures it can be determined whether the circuit is functioning correctly. The frequency and power level of the artificial signal are selected so that they approximate the frequency and power level of the normal signal at the sending point.

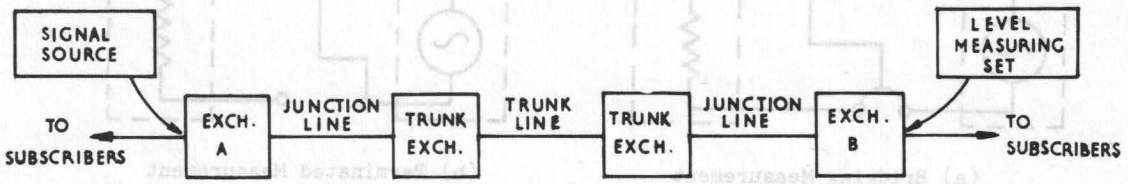


FIG. 44. POWER MEASUREMENT.

The signal source is generally an oscillator with facilities to vary the frequency and amplitude of its output (see section 11). The main component of the level measuring set is a high impedance voltmeter, the scale of which is set out to provide a reading in dBm. Other components included in a typical L.M.S. (Fig. 45) are various terminating impedances, an amplifier and a range switch.

Errors can easily occur when making power level measurements if certain precautions are not observed. One of the most important factors to be taken into consideration is that of impedance. The impedance offered by the L.M.S. in relation to the impedance offered by the circuit under test must be taken into consideration if errors are to be avoided. Because a voltmeter is used to measure power levels, the readings obtained will only be accurate under certain specified impedance conditions. Other precautions to be observed when measuring power in communication circuits are described in other papers.

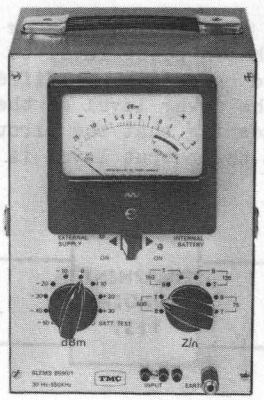
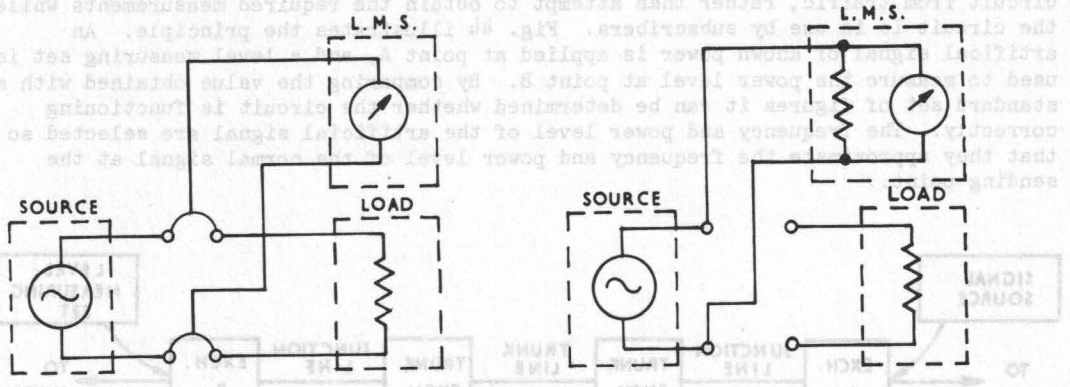


FIG. 45. TYPICAL LEVEL MEASURING SET.

8.3 BRIDGING AND TERMINATED MEASUREMENTS. The level measuring set can be connected to measure the power at a point in a circuit in two basic ways. One method is to "bridge" the instrument across the circuit as shown in Fig. 46a. In the other method the circuit is opened and terminated in an artificial load of known impedance, and the instrument is used to measure the power dissipated in the known impedance (Fig. 46b). The first situation is known as a bridging measurement and the second situation is known as a terminated measurement. Note that in the first case the through connection is not broken.

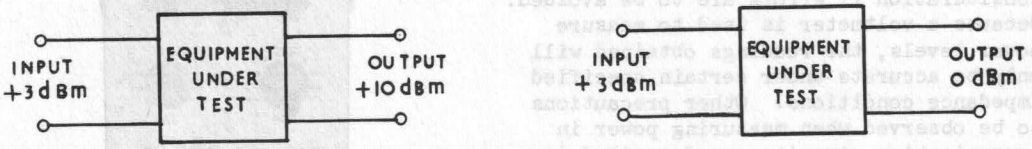


(a) Bridging Measurement (b) Terminated Measurement

FIG. 46. BRIDGING AND TERMINATING MEASUREMENTS.

8.4 GAIN AND LOSS MEASUREMENTS. When an item of equipment increases the power level of a signal it is said to have a gain. Conversely, when an item of equipment decreases the level of a signal it is said to have a loss. In many situations it is necessary to know the gain or loss of items of equipment, particularly when planning the connection of trunk circuits. The gain or loss of an item of equipment is expressed in dB.

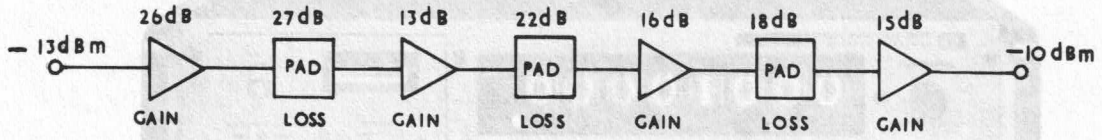
One way of finding the gain or loss (in dB) of a communication circuit is to apply a signal of known power level to the input of the circuit, measure the level at the output, and calculate the difference between the two levels. For example, in Fig. 47a the power level at the input is +3 dBm and the level at the output is +10 dBm, meaning that the circuit has a gain of 7 dB. In Fig. 47b the input level is +3 dBm and the output level is 0 dBm giving a loss of 3 dB.



(a) 7 dB Gain (b) 3 dB Loss

FIG. 47. GAIN AND LOSS MEASUREMENTS.

8.5 OVERALL GAIN OR LOSS. Most communication circuits comprise several items of equipment, and a signal applied to the input is subjected to both power losses and power gains. The overall gain or loss of the circuit can be found by applying a signal at the input, and measuring the power level at both ends. The overall gain or loss in dB is the difference between the two readings. (Fig. 48).



Total gain = 26 + 13 + 16 + 15 = 70 dB

Total loss = 27 + 22 + 18 = 67 dB

Overall gain = 3 dB

FIG. 48. OVERALL GAIN OR LOSS.

9. FREQUENCY MEASUREMENTS.

9.1 GENERAL. Frequency measurements are used in the installation and maintenance of telecommunications equipment as a means of checking that equipment and systems are operating correctly. The frequency of a signal can be specified provided the signal is periodic, that is, provided the signal comprises elements which recur regularly. The signals in Figs. 49a and b are periodic and therefore the frequency of each signal can be specified. It is meaningless to talk of the frequency of a signal which is not periodic.

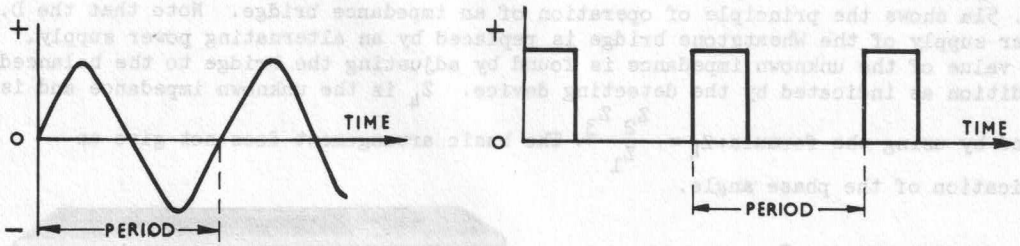


FIG. 49. PERIODIC SIGNALS.

The standard unit used to measure frequency is the hertz which is defined as the frequency of a periodic phenomenon of which the period is one second. In the case of A.C. a frequency of 1000 Hz means that 1000 complete cycles occur in a second. In the case of pulse signals the term pulse repetition frequency is used.

Many different methods and instruments are used to measure the wide range of frequencies encountered in telecommunications. For low frequencies such as those associated with power supplies instruments are often used which depend on interaction between electrical and mechanical forces (explained in other papers). For higher frequencies there is a choice of a wide range of instruments, the most common being the digital frequency counter and the oscilloscope. The digital frequency counter contains a counter which counts the number of cycles or pulses in a given period of time and provides a visual indication in digital form (Fig. 50). Para. 7.4 gives a brief description of how an oscilloscope can be used to measure frequency.

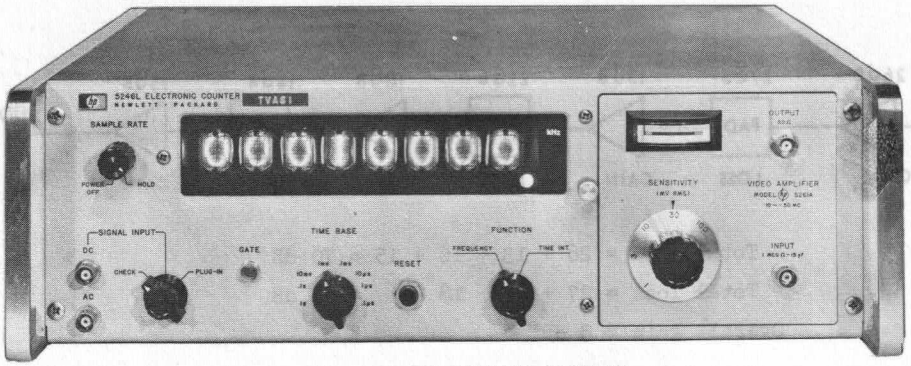
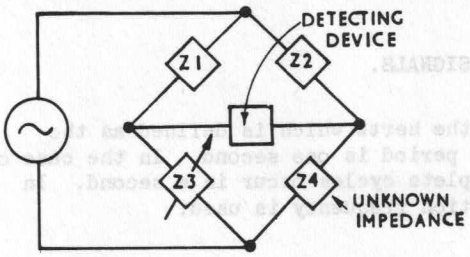


FIG. 50. FREQUENCY COUNTER.

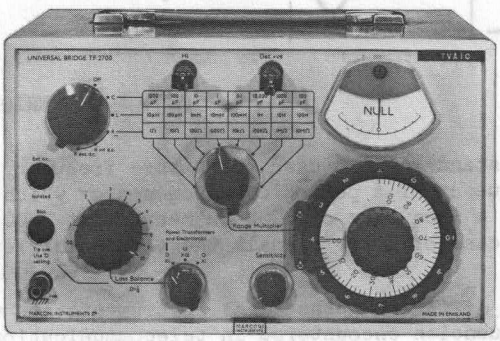
10. IMPEDANCE MEASUREMENTS.

10.1 GENERAL. Impedance measurements are concerned with the magnitude and nature of the opposition of a component or network to the flow of A.C. current. Not only is a measure of the total opposition to current flow required, but it is also important to determine the ratio of reactance to resistance and whether the reactance is inductive or capacitive. Impedance measurements are stated in ohms together with an indication of the phase relationship between the circuit current and voltage. The phase relationship can be stated either in radians or as an angle in degrees.

10.2 IMPEDANCE MEASUREMENTS can be made with the aid of a bridge circuit which operates on similar principles to the Wheatstone bridge described in para. 5.4. Fig. 51a shows the principle of operation of an impedance bridge. Note that the D.C. power supply of the Wheatstone bridge is replaced by an alternating power supply. The value of the unknown impedance is found by adjusting the bridge to the balanced condition as indicated by the detecting device. Z_4 is the unknown impedance and is found by using the formula: $Z_4 = \frac{Z_2 Z_3}{Z_1}$. The basic arrangement does not give an indication of the phase angle.



(a) Principle.



(b) Typical Bridge.

FIG. 51. IMPEDANCE BRIDGE.

The basic bridge circuit can be adapted to measure capacitance, inductance and capacitive or inductive reactance. In practice many different types of impedance bridges are used in specialised sections of the Department, and many provide a direct reading in ohms together with an indication of phase angle. Fig. 51b shows a typical impedance bridge.

11. SIGNAL SOURCES.

11.1 GENERAL. In many situations a test signal is applied to communication equipment and measurements are made at various points in the circuit to ensure that the equipment is functioning correctly. For example, when checking power levels in transmission circuits in section 8 a signal is applied to the input of the circuit and the power is measured at various test points (Fig. 48). In section 7 waveform examination is carried out by using a signal source to provide a specific waveshape at the input to a circuit. Test signals (sometimes referred to as artificial signals) are obtained from signal sources which are designed to provide signals having suitable frequencies, amplitudes and waveshapes.

A wide range of signal sources is available. They range from those providing a low frequency sine wave output to sources which provide words in the form of pulses to enable computer circuits to be tested. Although dividing lines cannot be clearly specified, most signal sources used by the department can be divided into three basic categories:

- Test Oscillators.
- Signal generators.
- Pulse generators.

11.2 TEST OSCILLATORS. Test oscillator is the name usually given to signal sources ranging from a basic oscillator to sources which comprise an oscillator together with a calibrated attenuator and an output monitor. In the latter type the oscillator provides a specified range of frequencies, the attenuator allows the amplitude of the output to be adjusted, and the monitor provides an indication of the actual output amplitude.

In most cases the output is in the form of a sine wave, but some test oscillators have facilities for the production of a square wave. A typical application of the test oscillator is its use to supply a signal of known frequency and power level to a circuit, to enable measurement of power levels at various points. Fig. 52 shows a typical test oscillator.

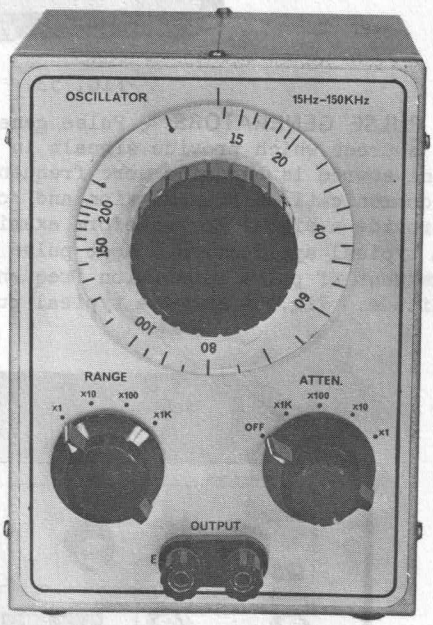


FIG. 52. TEST OSCILLATOR.

11.3 SIGNAL GENERATORS. The name signal generator is generally applied to those signal sources which are capable of providing a modulated output signal. At many points in modern communication systems, information is transmitted in the form of modulated signals. To enable tests to be carried out on equipment carrying modulated signals, signal sources are required which are capable of producing modulated signals similar to those present at various points in a circuit under normal circumstances.

Signal generators which provide amplitude, frequency and pulse modulation are available. The use of a signal generator to provide a modulated signal for testing broadband radio transmission equipment is a typical example of the use of signal generators. Fig. 53 shows a typical signal generator.

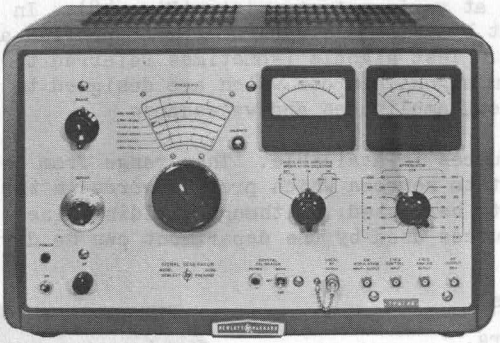


FIG. 53. SIGNAL GENERATOR.

11.4 PULSE GENERATORS. Pulse generator is the name used to describe those signal sources which provide signals in the form of pulses. The use of this type of signal source is becoming more frequent as digital techniques are introduced into telecommunications transmission and control equipment. The use of a pulse generator to provide a signal for waveform examination purposes at various points in a circuit is a typical application. Most pulse generators have facilities which allow adjustment of pulse repetition frequency, pulse width, rise and fall times, and pulse amplitude. Fig. 54 shows a typical pulse generator.

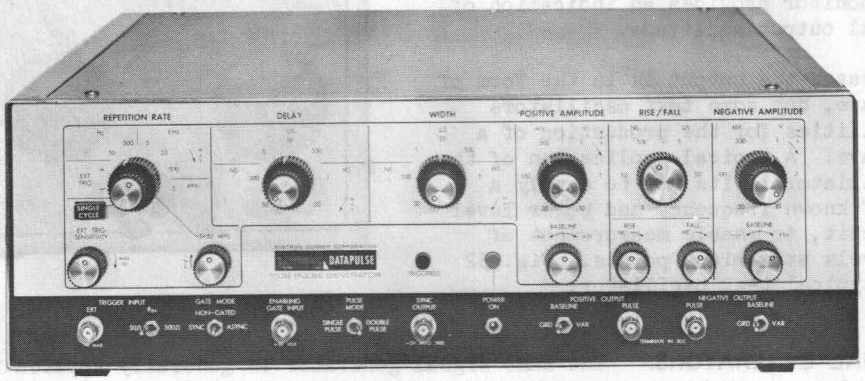


FIG. 54. PULSE GENERATOR.

12. PRECAUTIONS.

12.1 Electrical measurements are an important aid in the installation and maintenance of telecommunications equipment, and it is essential that you develop confidence and skill in making measurements related to the field in which you work. The following list summarises the precautions described in previous sections and adds some general hints which, if observed, will assist you to make reliable electrical measurements:

- Select the correct measuring instrument for the measurement to be taken.
- Allow the instrument time to warm up, if necessary.

- Ensure that the instrument is in the correct position, vertical or horizontal.
- Check the zero adjustment, and adjust if necessary.
- Select the highest range first and adjust the range switch as required.
- Ensure that all connections made are as low resistance as possible.
- Remember that in some cases measuring instruments used incorrectly can damage circuit components.
- Avoid parallax errors when using pointer type measuring instruments.
- In general, don't try to read the instrument more closely than the smallest printed scale division.
- Be consistent in "rounding off". Always read to the nearest scale line, and when the reading is halfway between lines, read to the nearest even division.
- Ask yourself "How accurate are these readings?" Factors to be considered are the accuracy of the instrument, how precisely the instrument can be read, and the effect the instrument has on the circuit.
- When making A.C. measurements:
    - Check the frequency range of the measuring instrument.
    - Check, if possible, the waveform of measured quantities. Remember that waveform distortion may cause inaccuracies.
    - Check what value the scale is designed to indicate (generally effective value unless otherwise specified).
    - Ensure that measuring equipment is properly earthed and screened if necessary.
- Avoid jarring measuring instruments, and keep them free from dampness and dust.
- Ensure that only the required component or network is across the instrument terminals when measuring resistance; open all other circuit paths.
- Don't use ohmmeters on energised circuits.
- Have instrument calibration checked regularly; leave this and all repairs to an expert.
- Observe all relevant safety precautions when measuring on high voltage circuits.

13. TEST QUESTIONS.

1. *State the standard units used to measure the following electrical quantities;*
   - *Voltage.* • *Impedance.* • *Current.*
   - *Frequency.* • *Resistance.* • *Power.*
2. *State the relationship between the standard units and the following multiple and sub-multiple units.*
   - *picofarad.* • *milliampere.* • *megohm.* • *decibel.*
3. *List four basic requirements of a measuring instrument.*
4. *Briefly explain what is meant by the following terms:*
   - *Scale.* • *Calibration.* • *Range.*
5. *With the aid of a diagram briefly describe the operation of a moving coil ohmmeter.*
6. *Briefly describe how the range of a moving coil D.C. ammeter can be extended.*
7. *With the aid of a diagram show how a moving coil instrument can be used to measure alternating current.*
8. *An 0-2 mA ammeter has a resistance of 75 ohms. What value of shunt will permit it to measure currents up to 50 mA?*
9. *Why is it necessary to ensure that ammeters have as low a resistance as possible?*
10. *With the aid of a diagram show how a moving coil ammeter can be converted to a voltmeter.*
11. *A 50 μA moving coil instrument has a resistance of 2 000 ohms. What multiplier resistance is required to measure 500 V full scale?*
12. *Why is it necessary to consider waveform and the way in which the scale is set out when measuring A.C. voltages?*
13. *Why is it necessary to ensure that voltmeter resistance is many times greater than the resistance of the component across which the instrument is connected?*
14. *Explain how a moving coil ammeter can be converted to an ohmmeter.*
15. *List two precautions which must be observed when using ohmmeters.*
16. *Explain the principle of operation of the wheatstone bridge.*
17. *With reference to Fig. 51, find the value of the unknown impedance (Z_4) when the ratio between Z_2 and Z_1 is 10:1 and Z_3 is adjusted to 1500 ohms.*
18. *What is the frequency of a periodic signal, one cycle of which occupies 5 μs?*
19. *Why is it necessary to measure power in telecommunications circuits and what is the unit used?*
20. *Explain what is meant by the terms "bridging" and "terminated" as related to power measurements.*
21. *Explain one method of determining the gain or loss of a communication circuit.*
22. *List the three types of information that can be obtained from a waveform displayed on an oscilloscope.*
23. *List the three basic types of signal sources associated with communications measuring equipment, and briefly describe the type of signal provided by each one.*
24. *List six precautions that should be taken when measuring A.C. voltage.*

END OF PAPER